X-band Observations of Waves, Algorithm Development, and Validation High Resolution Wave-Air-Sea Interaction DRI

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LONG-TERM GOALS

Our goal is to better understand physics of the air-sea interface including ocean wave generation, wave propagation, and air-sea fluxes.

OBJECTIVES

The potential to generate deterministic descriptions of the ocean's surface at elevated sea states using both modern observational techniques and computationally intensive, nonlinear wave models now exists. Investments in research to successfully validate and improve these techniques and models will improve the planning and execution of at-sea naval operations and further our understanding of air-sea interaction processes.

While signatures of the sea surface (sea clutter) are visible in the near range (< 3 nm) of any nautical X-band radar image, this information is generally filtered by the radar due to its design for navigation purposes. The sea clutter is a result of the backscatter at X-band principally composed of the Bragg scatter from O(1) cm scale capillary-gravity waves which are modulated by the underlying long ocean waves. As a result, sea clutter is a rich signal which contains information about the 2-D structure of ocean waves. Successful measurement and interpretation of the clutter may lead to an ability to reconstruct ocean wave heights over the domain observed by the radar. The objectives of this program are to research our ability to generate phase-resolved maps of the ocean sea surface.

APPROACH

We have successfully completed our 2nd year of the 5 year Hi-Resolution (HIRES) Defense Research Initiative (DRI). Our experimental approach for the program is a series of field programs designed to gather data, test new instruments and algorithms, and the synthesis of data. Our primary system for collecting X-band radar backscatter is the WAMOS radar acquisition system interfaced to a Furuno marine radar. WAMOS can be configured for both raw backscatter data acquisition and realtime processing of radar data for bulk wave parameters (non-phase resolved). For our research, the system is primarily relied upon for acquiring raw radar backscatter for subsequent offline processing. Ocean Waves (Konny Reichert, Associate PI of this grant) continues the development of improved algorithms

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for realtime processing of radar data for bulk wave conditions such as significant wave height (Hs) and the directional wave spectrum.

WORK COMPLETED

Several milestones have been achieved as part of this program. These include:

1. The development of GPS-based timing for purposes of synchronizing data collection from a marine radar.
2. At-sea tests to calibrate the internal gain amplifiers of a Furuno radar and the WAMOS data acquisition system.
3. Development of the signal processing framework for processing radar backscatter to generate maps of the ocean wave field. This framework has been tested in developmental algorithms and tested on multiple data sets. Improvements will come with comparison against ground truth data sets.
4. Data collection of ocean backscatter measurements over a range of sea conditions from the Scripps Pier. Measurements were also conducted in conjunction with airborne measurements of the seasurface using LIDAR with fellow HIRES investigator Ken Melville. Data from these tests serve as test data sets for algorithm development and validation.
5. Development of a suitable mounting system on the R/V Sproul and the participation in at sea tests (May21-June6, 2009).
6. Development of a vertical boom system onboard the R/P FLIP to support the radar system and the deployment of the radar during a test cruise. (July 6-14, 2009).
7. Deployment of the radar system in a ‘stand alone’ configuration as part of the RADYO field experiment offshore Hawaii on the R/P FLIP (August 26-September 16).

PRELIMINARY RESULTS

Our approach to processing radar backscatter has been to process the data in the spectral domain. Sequences of radar scans (Figure 1) are processed and filtered with 3D FFT techniques to determine the signal content attributed to ocean waves. Critical to this filtering process is the identification of the portion of the radar backscatter signal that follows the ocean wave dispersion relationship. Engineer Tony Depaolo has developed prototype algorithms which are run in a non-realtime mode to process the radar data, with attention paid to determining the ocean currents upon which the waves are riding. An example of radar backscatter is shown in Figure 1 and a map of the phase resolved surface wave field determined by our processing routines are shown in Figure 2.

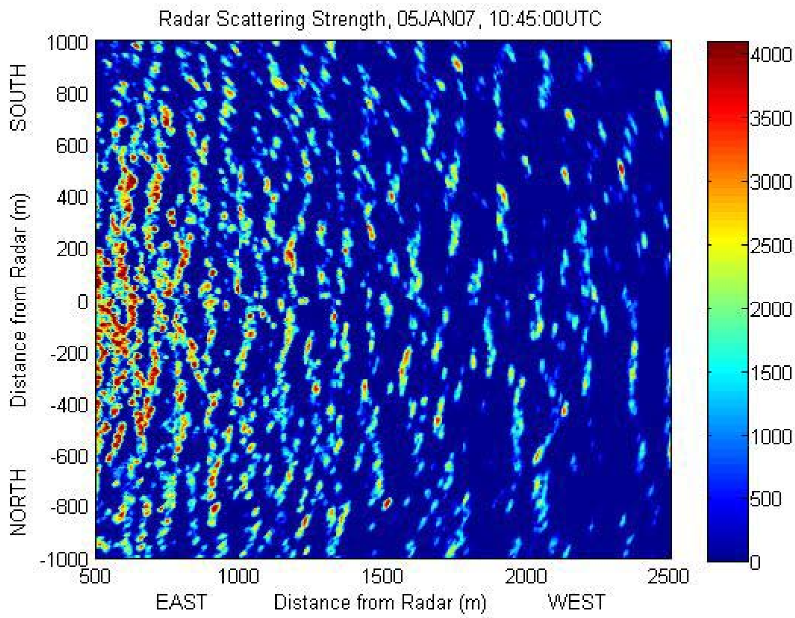

Figure 1. An example radar backscatter image. The domain shown is 2km x 2km and the color values shown represent 12bit resolution of the A/D programmed to sample the radar backscatter.

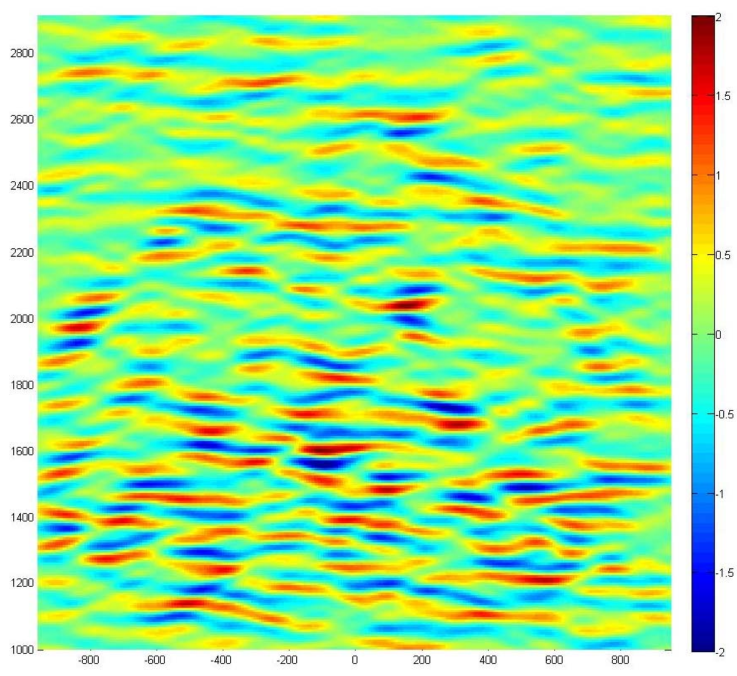

Figure 2. An example of the phase resolved sea surface. Ocean wave heights are mapped to -2m to 2m in elevation. The waves are propagating from top to bottom.

Efforts to verify the accuracy of the radar algorithms has been underway using independent measurements of the ocean wave field using wave buoys and airborne LIDAR. The two techniques are complementary as buoys can provide a point measurement of the waves as a function of time while airborne LIDAR scans a swath of the sea-surface to provide a ‘snapshot’ of the sea surface only time aliased by the speed of the aircraft. Figure 3 illustrates our efforts to resolve radar data (typically over a 2km x 2km box) with airborne LIDAR which has a much smaller swath width. Shown are the radar-derived wave heights mapped to the same time/spatial reference frame (Figure 3 - bottom) as represented by the LIDAR resolved sea surface (Figure 3 - top)

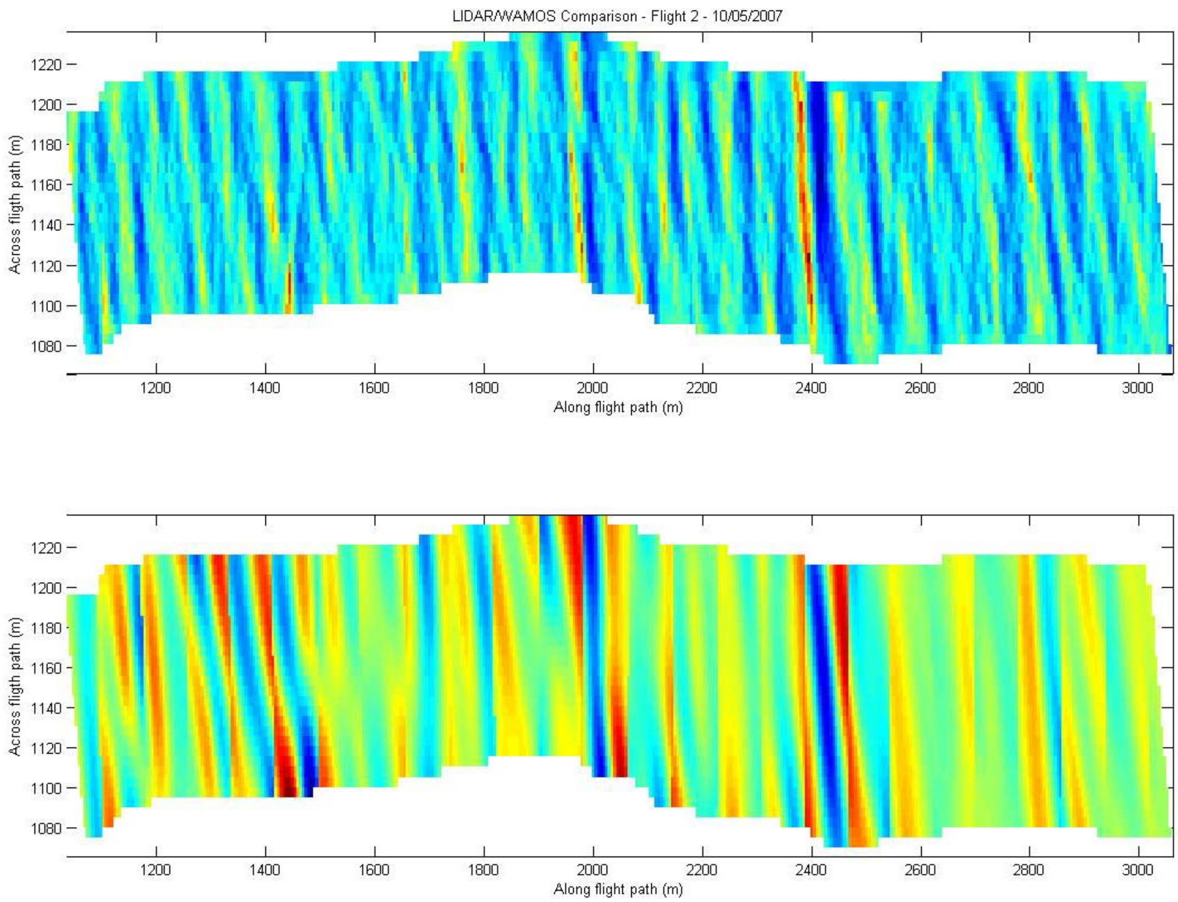

Figure 3. Top. LIDAR resolved ocean wave field provided by the airborne LIDAR system developed and operated by HIRES investigator Ken Melville. Along-flight distance is the horizontal axis and the swath width is the vertical. The aircraft has a speed of approximately 50m/s. Bottom. The radar-derived wave field over the same space-time domain.

An example of the skill of the radar to map wave heights, as compared to the LIDAR is shown in Figure 4. While the figure is encouraging in that the crests and troughs of the waves are aligned, clearly additional research is needed to improve the agreement between the two data sets.

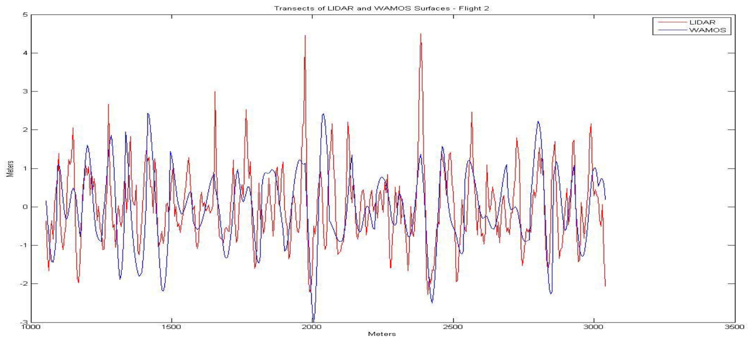

Figure 4. A cross-section of the ocean's surface as resolved by airborne LIDAR (red) and x-band radar (blue).

As a result of this summer's field work, we now have a large set of data to evaluate in anticipation of the upcoming HIRES field experiment scheduled to take place June 2010. A primary constraint of the field experiments in June were the presence of light winds which did not create an optimal level of radar backscatter. Nonetheless, the field efforts provided valuable insight in how best to deploy multiple wave measuring assets including arrays of wave measuring drifters. A number of engineering issues were also identified including the need for improved synchronization between our motion packages and the radar timing, improved heading alignment (sub-degree) of the radar is need for comparison with airborne data, and improved ship positioning with regards to drifting wave buoys. Another challenge experienced in the standalone deployment of the radar system onboard FLIP during the RADYO experiment was the need for ruggedized power systems. The radar experienced a failure of its uninterruptible power supply (UPS) which required staff onboard FLIP to route alternate power cables to the radar system. Despite this failure, we were able to obtain what we believe to be the first data set (7 day duration) of radar backscatter over a 360 degree field of view from FLIP. Data from these field experiments will be analyzed over the coming months in anticipation of the upcoming main field experiment in 2010.

Figure 5. Photograph of the R/V Sproul dockside with the X-band radar tower installed. The tower is designed to be above all other objects so that it has a clear field of view.

IMPACT/APPLICATIONS

The ability to remote sense ocean waves from an at-sea craft has numerous naval applications including seakeeping for mobile offshore bases, ship-ship transfers of materials, helicopter operations, and maneuvering in high seastates. It is expected that lessons learned from the HIRES DRI will support efforts in Future Naval Capabilities (FNC) programs.